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A Comparative Analysis of Climate Variability in Mingora, District Swat: Decadal Weather Shifts and Urban Impact

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ABSTRACT

This is a qualitative study that examines decadal weather changes, memory of the environment and vulnerability to urban hydrometeorology in Mingora of District Swat. By synthesizing the stories of senior community elders, local business people and district administrative officials, the research reveals a compound climate transition with three interconnected environmental shifts: a lost winter baseline with the permanent upward shift of the snowfall line on the valley floor and a decreasing frost period, a transformed monsoonal regime with the disappearance of the traditional multi-day drizzle or 'rim-jhim' and an increasing number of high-intensity short-duration cloudbursts, and an escalating summer urban heat island effect as a result of increasing ambient temperatures and rapid concrete densification. The study identifies the interaction between these modified atmospheric conditions and anthropogenic vulnerabilities – namely high density commercial and residential development along natural stream channels (khwars) and uncontrolled solid waste accumulation at municipal culverts. This relationship leads to a chain reaction of severe snowfall to flooding events that transforms a cloudburst upstream into a sudden inundation in the urban area, resulting in extensive socio-economic impacts, loss of infrastructure and displacement of households, as seen during the flood events of 2010 and 2022. To shift District Swat from the reactive post-disaster relief to pre-emptive climate resilience, the paper proposes a multi-scalar framework of adaptation that involves robust implementation of the floodplain setbacks in the framework of the Khyber Pakhtunkhwa River Protection Act, the removal of unauthorised encroachments on the river, the introduction of community-based cloudburst early warning systems and the planned expansion of green infrastructure in the municipality of Mingora while desilting the existing municipal drainage.

Keywords: *Decadal Weather Shifts, Mingora, Urban Flood Vulnerability, Stream Encroachments (Khwars), District Swat, Climate Adaptation.*

Overview of District Swat's High-Mountain Microclimate and Mingora's Urban Centrality

District Swat is part of the Hindu Kush mountain range in the northwestern part of Pakistan, and has a complex topography with steep topographic gradients, high altitude alpine ridges and narrow riverine valleys. It is a mountainous topography which generates its own unique high-mountain microclimate which is controlled by two major and dominant atmospheric regimes, namely the Western Disturbances in the winter months and the South Asian Summer Monsoon system (Atta-ur-Rahman & Khan, 2013). In the past, these regional atmospheric dynamics created a fairly stable, regular seasonal pattern, with high snowfall in the higher ridges / upper valleys, slow melt during spring, warm summers, and seasonally limited precipitation, (Akhtar & Ahmad, 2021). The microclimatic balance in the past helped sustain abundant alpine plant species and helped to ensure stable perennial stream flows, while also providing a foundation for local mountain agriculture on the valley floor.

Mingora is located along the lower reaches of the Swat River valley at an average elevation of around 984 m and serves as the major urban, economic and demographic hub of District Swat (Tariq & van de Giesen, 2012). In the last 40 years, Mingora has experienced a process of unplanned and unmanaged urban growth, evolving from a small commercial market town to an intensively developed urban space (Rentschler & Kornejew, 2026). Mingora is the administrative and commercial hub of the region and connects the resource-dependent rural areas in the upper Swat valley to the overall market network of the KP region. The city focuses the district's main retail, transportation, medical and educational facilities in a geographically narrow river valley, which results in high population densities and a high level of spatial competition.

This spatial concentration of human infrastructure and capital, however, also results in a high density vulnerability node, where macro-scale atmospheric variability meets micro-scale anthropogenic transformations (World Weather Attribution, 2025). Changes in natural land cover, agricultural land use, and riverine floodplains into impermeable surfaces like concrete highways, commercial blocks and informal residential settlements have fundamentally impacted local surface energy budgets and water response times (Tariq & van de Giesen, 2012). Urban debris in Mingora has encroached on, narrowed or constricted natural drainage conduits and seasonal streams (khwars) (Atta-ur-Rahman & Khan, 2013). This has made Mingora very vulnerable to the hydro-meteorological risks, and made localised extreme weather events more pronounced due to the built environment.

A Historical Climate Profile: Winter Snowpack to Seasonal Instability.

District Swat has historically had a seasonal climate profile with distinct boundaries in terms of temperatures and water availability. The region experienced significant snowfalls in the late autumn to winter months (November to March), which often reached higher altitudes and regularly reached lower valley floors close to Mingora and Saidu Sharif (Iqbal, 2026). The winter snowpack was a very important natural resource, providing a natural source of water that was regulated over the spring thaw period, to sustain downstream ecosystems, to irrigate local agriculture, and to provide a steady baseflow of the Swat River. In the same way, historical monsoon rains were generally recorded as continuous and lasting summers rains (rim-jhim) which would refill the soil moisture without causing any sort of serious land degradation or any catastrophic surface runoffs (Akhtar & Ahmad, 2021).

However, the last few decades have seen meteorological observations, empirical climate research and local oral traditions showing a significant departure from this historical baseline (Jamal & Rehman, 2025). The overall warming in the Hindu Kush region has led to uniform temperature changes, with increases in mean temperatures and changes in the timing of the seasons (Fatima, 2025). Consequently, the winter season in District Swat is getting shorter and shorter. The lower Swat and urban Mingora were witnessing a significant decrease in the amount of winter snow, with winter rainfall occurring in short bursts, with little to no snow accumulation (Iqbal, 2026).

At the same time, the precipitation timing, intensity, and spatial distribution in District Swat has been found to have been significantly destabilised (Jamal & Rehman, 2025). The regular snow-driven winter hydrological cycle is being driven more and more by more irregular events of concentrated rain. In the summer monsoon season, the area is seeing more frequent occurrences of localized cloudbursts, and heavy short-duration downpours (World Weather Attribution, 2025). The higher temperatures of the environment increase the snow and glacial melt in the upper Swat area and decrease the moisture storage available during the dry season resulting in higher flash runoffs during intense rainstorms (Atta-ur-Rahman & Khan, 2013).

The city in Mingora, especially the urban tributaries of the Swat River, are currently facing the challenges of rapid discharge surges and unstable flow fluctuations due to the lack of a consistent and reliable hydrological cycle that was once provided by snowmelt (Jamal & Rehman, 2025). Short duration, high intensity rainfalls on surrounding deforested slopes and impermeable urban surfaces cause storm runoff to quickly flow into local stream channels, causing municipal drainage capacity to be exceeded (Tariq & van de Giesen, 2012). This decadal shift – from a snowbound mountain valley with a predictable climate to an unstable, flash flood prone urban climate – highlights the need for qualitative empirical research that explores the perception, experience and response to these altered weather baselines in Mingora, District Swat.

Problem Statement

While the macro-level meteorological models and regional climate assessments provide a broad picture of changing temperatures over the Hindu Kush-Himalayan region, these types of analyses often mask the finer details of climatic conditions in the region. At the high-mountain riverine valleys, global and national climate datasets are not sufficiently detailed at the spatial scale needed to reflect localised microclimatic change and to directly link to the socio-economic impacts at the scale of specific human settlements. As such, the empirical question of how macro-scale atmospheric variability manifests at the micro-level of lived reality in the rapidly urbanizing mountain hubs such as Mingora (District Swat) remains an important gap.

The scientific literature in the region is rich on the topic of large-scale hydrological disturbance but the qualitative evidence—such as indigenous memory of the environment, oral testimony and local reporting of the disappearance of winter snow, irregular monsoon rainfall and frequent floods—is not given enough attention in Mingora. Mingora is the economic and commercial hub of District Swat, which is simultaneously being faced with a challenge of unchecked urban growth and heightened weather insecurity. The natural drainage capacity of the city is significantly weakened by the transformation of natural floodplains into dense built-up areas, and by the urbanisation of local stream channels (khwars). If such long-term residents, local traders, and municipal actors are not qualitatively understood and engaged in climate adaptation policies, then they may continue to be abstract and top-down. Current disaster preparedness structures in District Swat heavily focus on disaster relief while neglecting disaster risk reduction efforts from communities. To address this critical gap, this study offers a qualitative, empirical analysis that focuses on local lived experiences to document the decadal shifts in weather and climate, to evaluate vulnerability in the urban context, while proposing context specific adaptation strategies in Mingora.

Research Questions

What is the opinion of decadal weather changes among the long-term residents, local agriculturalists/traders and district officials in Mingora, District Swat?

What are the effects of heavy snowfall, long winters, and now intense and irregular rainfall, or riverine / urban flooding on the infrastructure and socio-economic life in Mingora?

Significance of the Study

The findings of this study have important theoretical and practical implications for the further development of climate adaptation and city resilience in high-mountain river valleys. Thematically, the research contributes to the literature on microclimatic changes in the mountains, qualitative disaster analysis in general and environmental memory in the Hindu Kush-Himalayas in particular, theoretically, by bridging the empirical gap between the macro-level of climate modelling and the micro-level of localized climate impacts in Mingora.

The implications of the results clearly inform the local disaster risk reduction (DRR) approach, community-based environmental planning and municipal climate adaptation plans at local level in District Swat and Khyber Pakhtunkhwa. The area has been facing the traditional top-down disaster management, which focuses on relief after an event rather than on risk management before an event. This study focuses on the operational context of local traders, long-term residents and municipal officials, offering actionable ideas that are grounded in the field.

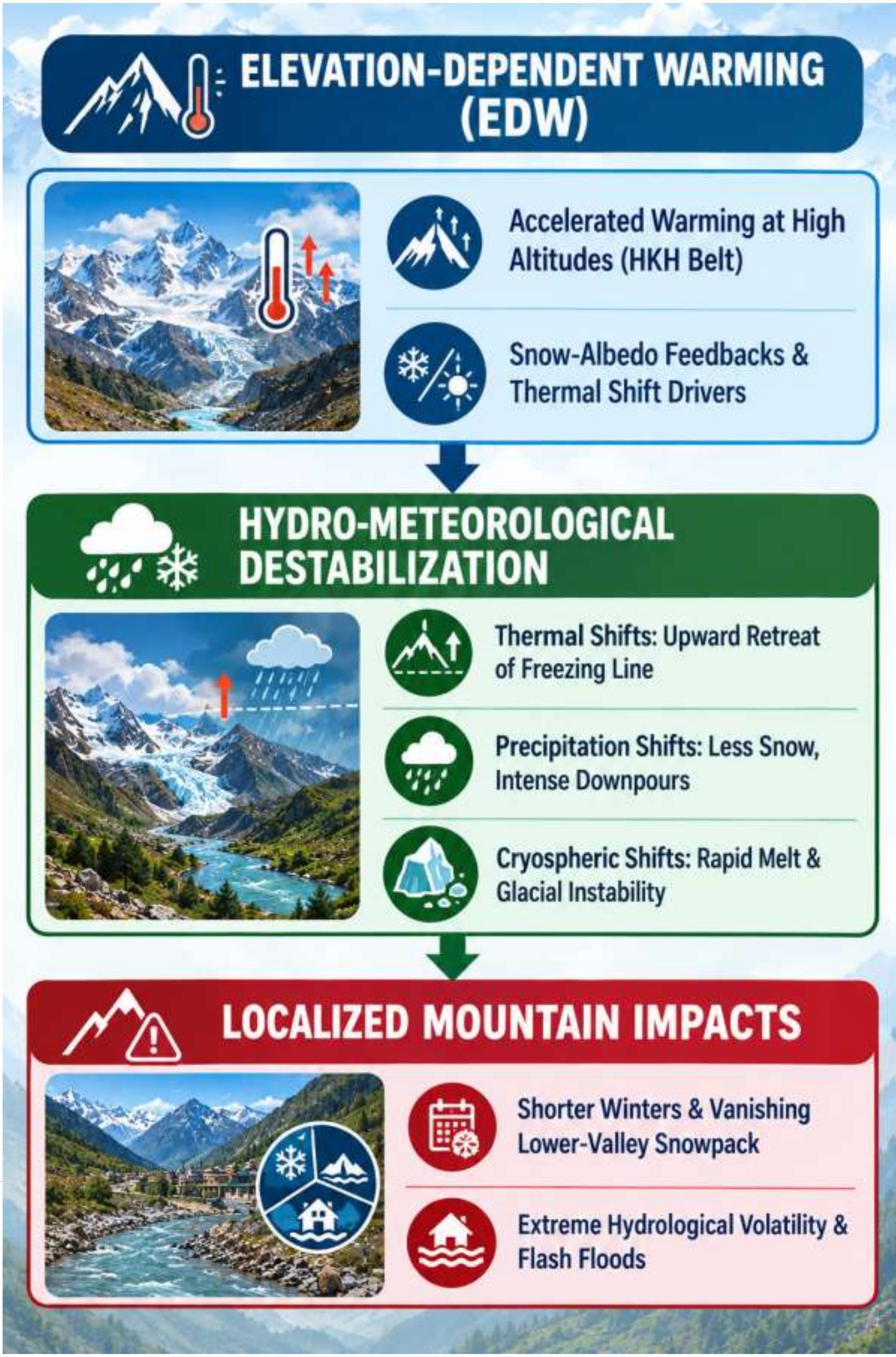
Specifically, the result provides proof-based recommendations for District Swat's administrative bodies to implement with regard to zoning of the riverbed and stream channels (khwar) and upgrading urban drainage infrastructure and creating community-based early warning systems. In conclusion, this study offers an adaptable qualitative approach for municipal planning towards incorporating local ecological knowledge into city master planning to make these vulnerable mountain commercial hubs into climate resilient urban centres.

The decadal climate variability in Northern Pakistan high mountainous valleys.

The Hindu Kush-Himalayan (HKH) region is one of the most hydrologically active, geologically complex and climatically sensitive mountain regions of the world. The HKH is a key region for controlling regional hydrology, thermal regimes and environmental stability throughout South and Central Asia, as it provides the headwater of major Asian river basins such as the Indus river system (Immerzeel et al., 2020). But, in the last few decades, the elevation-dependent warming over the HKH mountain belt has been greater than the global terrestrial average, as observed in climate science (known as Elevation-Dependent Warming or EDW) (Pepin et al., 2015). For high-altitude regions, EDW occurs as increased warming at higher altitudes due to snow-albedo feedbacks, shifts in water vapor and surface energy changes (Pepin et al., 2015). This decadal-scale warming trend has compromised the long-standing microclimates, changed cryospheric processes and affected the seasonal climate normals (Wester et al., 2019) across northern Pakistan, including the mountain ranges of Khyber Pakhtunkhwa (KP) and Gilgit-Baltistan.

Increased mean annual temperatures, more days of warm extremes, and a distinct winter season reduction are observed across northern Pakistan (Aamir & Hassan, 2024). Historically, the valleys of high mountains like the Swat Valley were also characterized by different thermal regimes: mid-latitude Western Disturbances in winter and South Asian Summer Monsoon system in the late summer season (Atta-ur-Rahman & Khan, 2013). The decadal trend of temperature across Khyber Pakhtunkhwa shows an increasing trend in winter temperatures which is reflected in an increase in freezing level altitude (UL Hasson et al., 2017). This elevation of the freezing threshold has directly affected the phase of winter precipitation (Ali et al., 2026), such that precipitation that used to occur as a persistent snow on mid-to-lower elevations of mountains is now occurring as a liquid rain. As a result, there is a spatial reduction in seasonal snow cover accumulation and an early melt thaw (Iqbal, 2026), the largest natural reservoir for the regulation of river discharge during spring and early summer season.

At the same time, the precipitation baselines in KP, especially across the region, have been given a good shake. Precipitation amounts in high mountain basins show high variability from one year to the next, but the time distribution, frequency and intensity of precipitation events has also changed significantly (Khattak et al., 2011). Empirical meteorological studies in Hindu Kush region have shown that rainfall is becoming more concentrated and intense in short-duration events, and less frequent and intense in distributed events (Jamal & Rehman, 2025). In the summer monsoon, the warming temperatures increase the moisture content of the air that flows through the valley, leading to localized rainfall events and heavy convective storms (World Weather Attribution, 2025). Such precipitation changes create extreme hydro variability in river basins such as the Swat River valley. In response to monsoon cloudbursts, mountain streams are now experiencing sudden discharge events, fast surface runoff and dangerous flash floods instead of regular streamflow driven by snowmelt (Khan & Rahman, 2018; Atta-ur-Rahman & Khan, 2013).


ELEVATION-DEPENDENT WARMING (EDW)
Accelerated Warming at High Altitudes (HKH Belt)
Snow-Albedo Feedbacks & Thermal Shift Drivers
HYDRO-METEOROLOGICAL DESTABILIZATION
Thermal Shifts: Upward Retreat of Freezing Line
Precipitation Shifts: Less Snow, Intense Downpours
Cryospheric Shifts: Rapid Melt & Glacial Instability
LOCALIZED MOUNTAIN IMPACTS
Shorter Winters & Vanishing Lower-Valley Snowpack
Extreme Hydrological Volatility & Flash Floods

Rapid Urbanization, Microclimates and Vulnerability in Mountain Hubs

The socio-spatial processes of urban development, land-use transformation and built-environment expansion (Blaikie et al., 2014; Wisner et al., 2004) are inherent to mountain communities and should not be overlooked in an understanding of their vulnerability to decadal climate variability. Topographically constrained valleys guide river flows and settlement in narrow corridors in high-mountain areas. Urban centres in these environments, like Mingora in district Swat, are important economic and demographic hubs, but are physically restricted by the adjacent mountain slopes and active river floodplains (Tariq & van de Giesen, 2012). In recent decades, these valley floors have experienced unmanaged urban growth due to increasing population growth, rural-to-urban migration and growing commercial populations in the high-hazard areas, resulting in dense, built environments (Rentschler & Kornejew, 2026).

Theories on urban microclimates and disaster vulnerability point to the fact that the surface radiation balances and hydrological characteristics of natural land cover are profoundly impacted when it is replaced by impervious artificial surfaces like concrete highways, masonry buildings and asphalt paving (Oke, 1982; Ward et al., 2020). In mountain villages, this spatial shift generates micro-temperatures higher than the surrounding rural hillsides in the form of an Urban Heat Island (UHI) effect, a build-up of solar heat in built-up areas (Gartland, 2012). Increased urban temperatures also have impacts on local thermal comfort, cooling energy needs, and may affect micro-scale convective cloud formation over valley basins (Taha, 1997). Rapid urbanisation in hubs of the mountain region has a very noticeable impact on the natural capacity of the mountain watersheds to absorb water. Vegetated soils and natural floodplains provide hydrological buffers in pristine or agricultural land-cover conditions, meaning that they can absorb rainfall, encourage infiltration and dampen peak storm flows (Dunne & Leopold, 1978). The increase in surface runoff coefficients and the decrease in hydrologic response times are dramatic with these natural surfaces replaced with impervious surfaces (Chow et al., 1988). When it rains heavily during cloudbursts or monsoonal rains, the rainwater has no chance to absorb by the impermeable urban soil but it immediately ends up as violent surface runoff.

In the towns, such as Mingora, this hydrological acceleration is aggravated due to the encroachments which include structural encroachments on natural drainage and seasonal streams known as khwars (Atta-ur-Rahman & Khan, 2013). In response to commercial real estate demands and insufficient municipal zoning controls, residential developments, commercial markets, and infrastructure are often built right within natural stream channels or historic floodplains (Rentschler & Kornejew, 2026). Moreover, lack of proper solid waste management systems leads to the narrow drainage system getting choked up with municipal wastes and thus significantly affects the hydraulic conveyance capacity of the pipe (Tariq & van de Giesen, 2012). As a result, during short-duration, high-intensity precipitation, rainfall on the deforested slopes and impermeable cities causes rapid storm runoff to reach natural or man-made channels, causing flooding.During short-duration, high-intensity rains, therefore, the surrounding deforested slopes and impermeable urban centers result in an increase in storm runoff that quickly exceeds the capacity of the natural or artificial channels, causing flooding. Combined with the growing density of humans and their constructions, changing the surface energy budgets and channel constriction, a high-density vulnerability node has been created, where localized weather events are transformed into catastrophic urban flood disasters (Wisner et al., 2004).

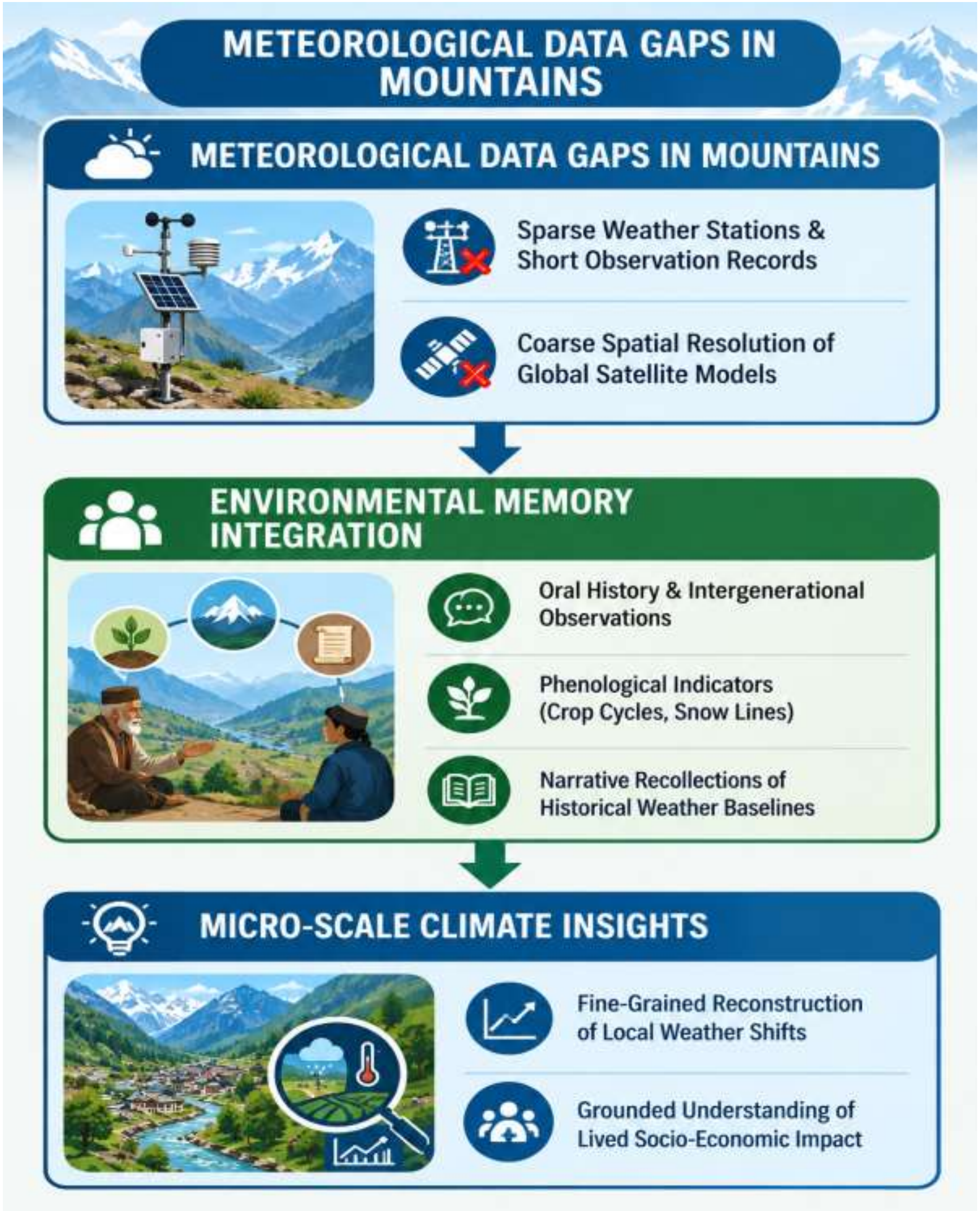
Lived Experience and Environmental Memory

In the mountainous areas of the developing world, fine scale instrumented meteorological observations are often limited by a lack of observational networks, short records, and data gaps due to difficult topography and logistical constraints (Pepin et al., 2015; Wester et al., 2019). Satellite observations have coarse spatial resolution and regional climate reanalysis products have a lower micro-spatial resolution, which is inadequate for resolving weather transitions in narrow mountain valleys (Atta-ur-Rahman & Khan, 2013). In response to this empirical gap, the lived experience and the oral history and indigenous environmental memory are now acknowledged as important sources for qualitative work in the field of climate studies (Cruikshank, 2005; Orlove et al., 2010).

Environmental memory is the community's collective, intergenerational knowledge and observations and the narratives that are remembered about past ecosystem states, seasonal cycles and weather patterns (Cruikshank, 2005; Naradasany et al., 2020). Local residents, traditional agriculturalists and long-term residents have well-developed memories of past environmental conditions—historical snow accumulation depth, traditional timing of thaws, nature of monsoonal rainfall, and historical flood boundaries (Nesshöver et al., 2013). Since human livelihoods in mountain valleys are closely intertwined with the weather cycles, local perceptions are very sensitive to the slight deviations from the historical weather cycles at decadal scale (Akhtar & Ahmad, 2021).

These lived environmental observations can be systematically documented and triangulated using qualitative methods that involve semi-structured oral history interviews and themed narrative analysis (Bryman, 2016; Creswell & Poth, 2018). The local narrative accounts are essential for giving the data a local context, which quantifiable meteorological measurements can't give alone. For example, the rain gauge measures the amount of precipitation in mm/day, whereas the oral report observes the effect of a change from ‘steady, multi-day rain (rim-jhim) to sudden cloudbursts' on the local farming calendar, on traditional building materials, or on perceptions of safety (Akhtar & Ahmad, 2021; Iqbal, 2026). Likewise, historical observations from winter snowline changes on surrounding mountain peaks contain empirical indicators of local temperature changes where there are no historical station records (Orlove et al., 2010).

Embedding environmental memory in climate research provides a real-world based, human-centred perspective on vulnerability and adaptation (Blaikie et al., 2014). Local stories are at the centre of providing a climate assessment, and it avoids the top down approach. Qualitative data collection from long-term elders, commercial traders, and local municipal workers can be used to build a multi-perspectival and rich record of the changes in weather exposures, structural urban changes, and disaster exposures observed in rapidly changing urbanizing valleys like Mingora, over the last decade or so (Atta-ur-Rahman & Khan, 2013; Jamal & Rehman, 2025).


METEOROLOGICAL DATA GAPS IN MOUNTAINS
METEOROLOGICAL DATA GAPS IN MOUNTAINS
Sparse Weather Stations & Short Observation Records
Coarse Spatial Resolution of Global Satellite Models
ENVIRONMENTAL MEMORY INTEGRATION
Oral History & Intergenerational Observations
Phenological Indicators (Crop Cycles, Snow Lines)
Narrative Recollections of Historical Weather Baselines
MICRO-SCALE CLIMATE INSIGHTS
Fine-Grained Reconstruction of Local Weather Shifts
Grounded Understanding of Lived Socio-Economic Impact

Methodology

The study follows purely qualitative research approach based on phenomenological approaches and oral history methodology (Creswell & Poth, 2018) to investigate the perceptions of climate variability, decadal weather shifts and vulnerability of the city of Mingora, District Swat. Phenomenological inquiry enables the researcher to consider the lived human experiences and the personal meaning attached by individuals to the phenomena of the environment and is well suited for considering what the communities experience in climatic transitions (Moustakas, 1994). At the same time, the oral history method offers a structured framework for accessing long-term environmental memory, and can help reconstruct historical weather baselines in contexts where there are few high-resolution and long-term meteorological station data or where they are generalized across space (Cruikshank, 2005).

For this reason, a qualitative paradigm is preferred to quantitative modeling, as numerical representation of climate indicators may not be able to adequately reflect the socio-spatial dimensions of climate impacts, localized economic disruptions, and experiential dimensions of climate impacts (Bryman, 2016). This design's focus is on human narrative to highlight the lived experiences of long-term residents, local economic actors, and administrative officials and to incorporate observations of fine-grained variations in snowfall, monsoon behavior, and urban flooding throughout District Swat.

Study Area: Mingora, District Swat

This study highlights the geographic study area as Mingora which has been the main urban, commercial and demographic epicentre of District Swat in Khyber Pakhtunkhwa. Mingora lies in a geomorphically restricted valley floor in the Swat river basin at an altitude of about 984 m with steep slopes rising from both sides. There are several important natural streams and tributaries (called khwars locally) in the city which flow directly into the Swat River from the surrounding mountain catchments (Atta-ur-Rahman & Khan, 2013).

Mingora has seen high population density, rapid commercialization, and conversion of natural land cover to impermeable built environments over the last few decades, with an intensity of unmanaged urban development that is unprecedented and uncharacteristic of smaller towns (Rentschler & Kornejew, 2026). The dense urban setup, the indiscriminate encroachments on natural khwar beds and solid waste dumping in khwar channels make Mingora extremely vulnerable to hydro-meteorological risks. Its location is also a key exposure point to surface run-off, sudden cloudbursts of the monsoons and riverine surges, causing surface flooding and flash flooding in the city on a regular basis.

The categories of Key Informants and the types of samples are described below.

In this study purposive and snowball sampling technique was used to select the key informants in different for selected districts in Swat (Etikan et al., 2016). The selection of the participants was done by targeting those who were residing in the area for a long period of time, had occupational exposure to changes in weather, and were involved in institutional activities in urban governance and disaster management. In order to achieve multi-perspective triangulation, the participants were segmented into three different key informant groups:

Senior Residents & Community Elders (Category A)

The category aims to identify community influencers who have lived in Mingora for 50 years or longer to provide long-term environmental memory and to map decadal weather changes. Senior community elders Speen Dada, Muhammad Alam (Kadada), Iqbal Khan, and Khursheed Khan, who are older than 60 years, are key informants. Their accounts provide historical baseline data for snowfall, thermal comfort in the winter months, and historical river levels.

Local Business Owners, Vendors & Farmers (Category B)

This group reflects the immediate socio-economic, operational and agricultural effects of climatic changes. In the emerald mining area of Haji Hayat Khan, Nawaz Khan and Rafiullah among the informants are businessmen with distinct views on the sub-surface hydrological changes, the terrain stability and seasonal nature of mining in Swat. Local vendors Arshid Khan and Abdul Raheem as well as local farmers Imran Khan share their views on agricultural and market conditions including fluctuation in seasonal crops, disruption of markets, and availability of irrigation water.

District Administration & Disaster Management Officials (Category C)

Key institutional actors and civil society leaders are part of this category to assess structural responses, policy enforcement, and municipal planning issues. Key informants are local lawyer and civil society activist Haidar Khan, and local Tehsil Municipal Officer (TMO) and Tehsildar from District Disaster Management Authority (DDMA) for enforcement of municipal zoning and implementation of the Swat protocol.

Semi-Structured In-Depth Interviews is one type of data collection technique.

Primary qualitative data was collected using semi-structured, in-depth face-to-face interview, with flexible pre-tested qualitative interview protocols (Kvale, 2007). Semi-structured interviewing provides an opportunity to allow participants to give voice to their experiences, whilst also giving flexibility to the researcher to explore emergent thematic areas (Bernard, 2017). Interview protocols were translated into Pashto (the dominant language in district Swat) and interviews were held in places that participants felt comfortable in to encourage trust and open dialogue.

The interviews were organized into four thematic clusters:

1. Historical Weather Baselines: Memories of past winter duration, snowfall depth and extent of winter freezing line in and around Mingora.

2. Precipitation & Thermal Transitions: Perceptions of changes in monsoon characteristics (historical steady rim-jhim rain with cloudburst and summer temperature changes).

3. Urban Vulnerability & Flooding: Perceived effects of encroachments on stream channels (khwar), drainage blockages and increased run-off rates during extreme rainfall events.

4. Institutional Response & Adaptation: Governance issues, weak municipal enforcement and coping mechanisms in major flood crises.

Data Analysis Strategy

The collected data of this interview will be analyzed by Systematic Thematic Analysis method that has been developed based on six phases of qualitative analysis proposed by Braun and Clarke (2006). All tapes were transcribed and translated word for word into English for analysis.

Familiarization: Repeatedly reading interview transcripts and field notes.

1. Initial Code Generation: Inductive open coding of specific environmental observations such as: "retreating snowline," "unpredictable cloudburst," "drainage blockage").

2. Clustering of related codes into broader: thematic categories representing decadal weather shifts, socio-economic impacts and urban vulnerability drivers.
3. Reviewing Themes: Triangulating themes across the three groups of respondents – elders, commercial actors, and district officials in order to achieve empirical consistency and validity.
4. Defining and Naming Themes: Clustering of the core conceptual themes to organize the empirical story.
5. The Report's production: They were using the direct speech of the participants to illustrate grounded qualitative results of the climate variability in Mingora, District-Swat.

Empirical Findings: Decadal Weather Shifts in Lived Experience

The Changing Winter Baseline: From snows to milder winters

Empirical qualitative evidence collected in the whole District Swat shows a significant structural shift from the past weather conditions during the winter period. In general, over the past 40 years or so, both the severity of winter and the amount of snow that falls during the season have decreased, and ground frosts are no longer as common as they once were, according to all long-term residents of Mingora, agriculturalists and local commercial actors.

The descriptions of winter that the Category A elders offer repeatedly consistently characterize it as cold and severe, with heavy snowfall being directly on the urban valley floor, in the mid- to late-1960s and 1970s. Senior community elder Speen Dada (70+) remembered his childhood days:

In the 1970's and early 1980's, in Mingora snow was on the ground for weeks at a time, and snow could be measured here in the main bazaar and residential streets, and men from all families would clear the snow with wooden shovels (kore), snow was not found anywhere else but in social media and high in Kalam for the young people of Mingora.

This is supported by Muhammad Alam Kadada, who highlighted the breakdown of function due to extreme frosts (yakh) and frozen sub-surface soils during the winter season.

“In the old days, the temperature fell below freezing early in November and winter persisted well into February, with water pipes often freezing over or even bursting; in the past small standing puddles on the roadsides would remain frozen all the way through the afternoon. But those days are gone; now winters are late (often not till late December), and they come early. One does not necessarily follow the other: the ground is no longer frozen in Mingora, and getting snow at the bottom of the valley has become rare, something that is usually present only occasionally.

However, there are also more than anecdotal observations of spatial elevation change, specifically, the long-term shifting of the winter snowfall line to higher elevations. All informants reported that heavy snow used to occur regularly on the foothill settlement areas from Mingora up to 900–1,000 meters but had started receding to higher elevation areas in Malam Jabba (9,000+ feet) and Kalam (6,800+ feet) in upper Swat.

In the case of livelihoods that are dependent on resources, it has direct economic implications. The businessmen engaged in emerald mining in the valley Haji Hayat Khan, Nawaz Khan and Rafiullah explained how changing underground temperatures and changing snow-melt cycles affect the logistical aspects of mining operations seasonally along the slopes of the valley.

In the past decades, heavy snowfall and ice form in the valleys during winter causing winter season closure of open cast and gallery mining due to inaccessibility of valleys. Today, with such mild winters and little snow in lower and mid-Swat, work can be carried on almost without interruption throughout January; but the absence of winter snow higher up results in unpredictable seepage of water in the galleries during spring, which was a major concern in the past.

Community elder Iqbal Khan related the loss of winter snow to other environmental and social changes throughout the district:

In Mingora, the loss of snow was not only climatic, but it was also ecological, as snow during the cold season helps clean up the streets, maintain springs and hold crop pests at bay.

The changing of the monsoon and the erratic rainfalls

The dry and warm winter story contrasts with a dramatic change in the summertime monsoon system in the summer record. Historical rain patterns were always compared with the today's high intensity short duration rain and violent localized rainstorms by the key informants.

Local Pashtuns refer to historical summer rains as rim-jhim, which means gentle, long duration and steady rains that never destroyed the surface suddenly and could last for 3–7 days. Senior elder Khursheed Khan brought up this qualitative change:

The monsoon is no longer gentle, drip-drip-dripping, but it's an assault: it now drops great amounts of water in a few hours, and then days of very hot dry weather. The streams (khwars) rise quickly and irregularly.

The change in the pattern of scattered drizzles to heavy downpours has increased the risks and vulnerabilities of agriculture and urban informal vendors. Farmer Abdul Raheem explained how the irregular rainfall interferes with the traditional farming schedule.

“Historically, we had an accurate knowledge of the start of the monsoon season with rain signals and what we were preparing in the field for the next six months, but with the unpredictability of the calendar, we are getting very severe dry periods at the time that crops need rain and then a cloudburst in one spot, washing away the farm soil, and the water running off the field like a torrent.

In the case of small-scale commercial players on the streets of Mingora, the erratic rains have a direct impact on the day-to-day economic activities of these actors. Along a well-trodden route, leading to the intersection of the major natural draining stream (khwar), street vendor Arshid Khan said:

Ten years ago, we could see the sky and know what kind of day it was going to be: soft rain. Now, an unexpected storm rises over the hills surrounding the city in 20 minutes' time; the rain comes down so quickly that we can't even get our wooden carts or goods under cover. It's not just rain—now it's sudden, focused rain that floods the city's drains in short order.

The effect of the unpredictable rainfalls also affects specific industrial areas. Emerald trader Nawaz Khan pointed out that short duration, but intense rainfalls are a big threat to the hillside mining activities:

In the past, heavy rain to catchment scale would provide warning but now, sudden cloudbursts to catchment scale will cause flash runoff in a tributary before people in Mingora even notice that it has started raining upstream.

The effects that temperature changes have in summer on thermal comfort.

The residents, business owners, and local administrative officials' narratives, collected along with seasonal precipitation changes, show an unprecedented rise in ambient temperatures and changes in thermal comfort in the Swat Valley during the summer season. Today, Mingora is celebrated as a vacation destination in the summer, but as the summer temperature and humidity continue to increase, older generations have no memory of a summer like this.

Senior resident Speen Dada recalled the historical temperature of Mingora:

I remember when the weather was cool in the summer between June and July and it was not worth buying electric fans or air coolers for us, we would sleep out in the night on the rooftops under a light blanket, while today it is not possible without a fan or air cooler.

These temperature changes have been intensified by the physical changes to the built environment in Mingora. The intense urbanization, the high density of concrete buildings and the scarcity of green space have created an acute urban heat island effect in the valley. Farmer Imran Khan commented on the synergistic impacts of microclimate warming and crop adaptation:

During summer afternoons in Mingora, the ambient heat is definitely noticeable and is leading to the change in pest populations and crop maturation cycles on the farms of the surrounding mountain valleys, which used to be much lower, but are now too warm.

Local consumption patterns and municipal needs of infrastructure are indicators of the socio-economic impact of increased temperatures during the summer. Civil society activist and lawyer Haidar Khan commented:

Now, air conditioners, which were virtually absent in Swat in the 1980s, are commonplace in commercial plazas, government offices and in homes; this has resulted in electricity blackouts and massive summer power surges, exacerbating the discomfort of the urban populace during hot summers.

These community narratives were also confirmed by local administrative officials such as the Tehsil Municipal Officer (TMO) and local Tehsildar, who acknowledged the unprecedented pressure on the municipal services and emergency response systems due to the thermal shifts and changing weather patterns.

The TMO said that the municipality is faced with a new extreme on both sides. These qualitative changes in weather described by the senior elders are no longer predictions of future climate but are challenges of everyday management in the city in District Swat.

These empirical stories, triangulated across the perspectives of senior community elders, commercial actors and district actors, attest to the compound climate transition that local communities are facing in Mingora—a lost winter baseline, irregular and unpredictable monsoonal delivery and increasing summer heat.

Urban Impact, Flooding, and Vulnerability in Mingora

The Snowfall-to-Flood Cascade

The qualitative evidence collected throughout District Swat shows that the snowfall-to-flood cascade is a direct and systemic relation to the local hydrological hazards which is linked to the atmospheric patterns that change. Over the years, high elevation winter snowpack served as a natural "hydrological sponge" which captured precipitation during the winter months and released it slowly over the late spring and early summer snowmelt period. This slow release ensured regular flows of water in the Swat River and its mountain tributaries (khwars) not to flood the settlement channels downstream.

Key informants point out, however, that the dramatic decrease in snowfall depths in the winter and the upward migration of the snowline have caused this sustaining mechanism to malfunction. However, if rainfall in the catchment areas during the winter is mostly in the form of rain, rather than snow, then topsoil saturation can happen too early on the slopes. As a result, during early summer heat wave periods when localized cloudbursts occur, the modified catchment surfaces are unable to absorb large amounts of rainfall.

To illustrate this cascade, Senior community elder Speen Dada (aged 60+) showed by comparison:

“In the past, the snow on the mountains was melting over four-five months and the streams (khwars) of water provided cold and clear water throughout and did not often burst their natural stone banks in early summer, now with little snow to absorb the early heat waves, the streams of water burst into the valley in hours, carrying mud, stones and debris, turning the calm streams into damage channels.”

This enhanced run-off situation is directly linked to the very dense system of natural streams of Mingora (Marghazar Khwar and Rahimabad Khwar) that drain the commercial and residential areas and merge into the main river of Swat.

Encroachments, Drainage, and Urban Vulnerability

Human land use dynamics and governance failures are a powerful amplifier of disaster risk in Mingora, despite the shifting precipitation regimes as a physical driver. Over the last three decades, the city's major khwars have experienced rapid unplanned urban growth and extensive commercial and residential encroachment of the natural flood plains and active channels.

Structural channel narrowing and solid waste accumulation were consistently mentioned as the main factors contributing to the worsening of monsoonal rainfalls to destructive urban floods across all informant categories. Haidar Khan, a civil society activist and lawyer, pointed to the failure of the systems to regulate themselves:

In Mingora, climate change is only part of the problem, human greed and neglect are the other factors. The natural flood channels which used to be fifty meters wide have been shrunk by concrete walls into narrow ditches less than ten meters wide and when a cloudburst occurs over the catchment, water has no place to spread but into commercial bazaars and living rooms.

Uncontrolled disposal of MSW is a structural restriction. Natural drainage areas are informal dump sites for commercial waste, plastic waste and building debris in low income, high-density informal settlements. Arshid Khan, a market vendor, elaborated how blockage of drains results in quick localized flooding:

In dry seasons, khwars fill up with plastic bottles, household garbage and debris, and when a heavy downpour begins, this floating waste spills over to the narrow bridges and culverts, leading to solid blockages in the khwar within 15 minutes, and the trapped water surges over into the surrounding streets and stalls of the market.

The Tehsil Municipal Officer (TMO) admitted that although rules for zoning are available on paper, it is difficult to enforce construction setbacks anywhere along the river in use because of the political price of the land and competing land rights.

Socio-Economic Disturbance and Major Flood Events

The experiences of the residents of Mingora make it evident that the socio-economic impact of the unmanaged hydro-meteorological hazards is quite profound, particularly during the periods of major floods in 2010 and 2022. They severely impacted local supply chains, damaged municipal infrastructure and caused mass displacement of households in lower and mid-Swat.

The memories of super-floods in 2010 are focused on the damage to the structures and length of time they were isolated. Emerald businessman Haji Hayat Khan said that sudden destruction happened in the corridor of Swat River:

Main bridges, roads, and commercial properties on the riverside were washed away by the Swat River, which led to the immediate shutdown of mining operations for a period of several months due to the loss of equipment, processing plants and the transportation access.

The flood of 2010 was a large riverine flood from an extended period of rainfall over the region, but the accounts from the flood of August 2022 emphasized the critical role for flash flooding along urban tributaries and riverine flooding. Local farmer Abdul Raheem described the heavy damages to the agriculture in the periphery of the river:

"In 2022, the water level climbed so quickly that farmers had no time to preserve the standing crops or livestock, as thick layers of infertile sand and gravel covered the fertile agricultural fields, eradicating topsoil each farmer had worked many decades to develop, with many small farmers on the banks of the river losing their entire season's income in one afternoon."

Floods result in overall financial crisis for informal urban labourers and small market vendors. Street vendor Arshid Khan said the problems in the urban street after flooding:

A day labourer or small retailer whose income is dependent on the market will take out loans just to be able to feed the family, if his or her market is closed for three weeks when the flooding occurs and the mud siltates the floor.

When linked together by elders, commercial actors and municipal authorities, these narrative accounts illustrate the interplay of changes to precipitation patterns and high-density channel encroachment, inadequate solid waste management, and structural policy enforcement gaps, to bring to the fore the vulnerability of urban spaces in Mingora, Pakistan.

These Regional Climate Trends are integrated into Local Environmental Memory

The region climate literature is in support with the empirical results obtained in Mingora region and meteorological projections in northern Pakistan. The changes in snowfall line uplift and the disappearance of the valley floor ground frost (yakh) and the reduction in drizzle (rim-jhim) in favour of heavy cloudbursts are backed-up by empirical observations made across the Hindu Kush Himalayan (HKH) region, of which the oral histories compiled in this study are representative. Climate dynamics studies in the catchments of the upper Indus basin are in general agreement that there has been a significant warming trend, especially in winter, which has been associated with melting of glaciers and increased rain-to-snow ratio at mid altitudes.

The documented changes in regional atmospheric circulation in the region, driven by the warming sea surface temperatures and changes in the jet stream, are echoed in the local perceptions of altered monsoonal delivery, as a rise in the number of localized and short duration extreme precipitation events is documented over a complex mountain terrain. Additionally, reports of increasing urban heat island effects in Mingora are consistent with other observations of rapid and uncontrolled urban growth in the mountain valleys, in which the high thermal albedo of buildings, rooftops, and the reduced albedo of the impervious surfaces for which they are built exacerbates the urban heat island effect and contributes to increased surface runoff. Local environmental memory in combination with scientific climate modelling supports the use of community based oral history as a powerful and differentiated tool for reconstruction of historical baselines in data limited mountain environments.

The region of District Swat is facing several policy gaps related to local climate adaptation. There are several gaps in policy for local adaptation in District Swat.

Although District Swat is facing increasing hydro-meteorological risks, institutional arrangements for disaster risk reduction and urban planning and governance are reactive, disjointed, and -in terms of climate adaptation- not really suited. The dilemma of municipal and district planning problems is because the national disaster policy instructions and administration power of the local administration are in a basic contradiction.

Key policy gaps identified

The reactive Emergency Management system: used by Municipal entities like Tehsil Municipal Administration (TMA) and District Disaster Management Authority (DDMA) does not employ proactive risk-reduction measures and focuses mainly on post disaster relief.

Weak zoning and building code enforcement: allows for continued building and commercial encroachments along natural stream channels (khwars) and along active river corridors.

Poor Drainage Infrastructure: Municipal Solid Waste (MSW) management systems are still very weak and under-resourced, and solid waste primarily culverts and drainage channels frequently clog during monsoonal rains.

Lack of localized early warning systems: Disaster management plans don't have fine-grained, localized early warning systems to alert dense urban neighborhoods and informal vendors to a cloudburst in the upstream areas.

These vulnerabilities need to be addressed with a different approach from the act-then-repair to integrated eco-centric planning of the urban space. This requires ensuring proper legal distance of the khwar corridors, reopening natural drainage channels, improving solid waste collection and incorporating community-based environmental knowledge into local disaster preparedness.

Conclusion & Recommendations

In the present qualitative study, decadal weather changes, local environmental memory and vulnerability of urban hydro-meteorological phenomena have been studied at Mingora, District Swat. The study triangulates the experiences of senior community elders, commercial actors, and district administrative actors to provide a compound climate transition process, consisting of three overlapping environmental changes. First, long-term residents say they observe a lost winter baseline – that the severity of winter has changed significantly over the last 40 years and more. The usual snowfall on the valley floor at Mingora has become less common and is now routinely requiring snow-removal services from the roof tops, as snowfall is now moving to higher elevations with extended winter temperatures and fewer frost days. Secondly, community experiences compare the traditional multi-day monsoon drizzle (rim-jhim) with the more recent short-duration, high intensity cloudbursts whose variable rainstorms lead to extreme surface run-offs which over-load natural drainage catchments and cause local agriculture and mining activities to stall. Third, high-density concrete construction in the valley has created a microclimate urban heat island effect with higher summer ambient temperatures, leading to the very quick uptake of mechanical cooling appliances by households and high summer stress on the electricity grid. Importantly, the study shows that those climate changes act directly with human-induced vulnerabilities. High-density commercial and residential encroachments along natural stream channels (khwars) combined with unmanaged solid waste obstruction of municipal culverts produce a serious snowfall to flood cascade. The heavy rainfall from cloud bursts upstream during the two floods in 2010 and 2022 has been associated with urban inundation, leading to socio-economic disruption, extensive damage to infrastructure and household displacement, due to these structural bottlenecks.

Ongoing structural reform, disaster early warning and sustainable infrastructure are crucial for a multi-scalar, eco-centric adaptation approach that creates a transition from reactive post-disaster relief to proactive sustainable climate-resilience in the District Swat. First, provincial authorities and the Tehsil Municipal Administration (TMA) need to strictly implement the setbacks and zoning requirements from the floodplain of the primary urban khwars and along the Swat River in accordance with the Khyber Pakhtunkhwa River Protection Act. This involves the ban and systematic elimination of illegal commercial plazas, residential extensions and permanent constructions that narrow natural stream channels and do not allow flood discharge, and the creation of GIS-mapped high-risk flood hazard zones along the Marghazar and Rahimabad khwars, where the construction of new structures is permanently forbidden. Second, the District Disaster Management Authority (DDMA) needs to strengthen multi-hazard data management and civil society involvement through the installation of automatic weather stations and river upstream gauge sensors in mountain catchments and in cooperation with the Pakistan Meteorological Department (PMD). These physical assets should be connected to community-based early warning systems with direct SMS notifications, the use of mosque loudspeakers and mobile applications, which can reach the street vendors, informal traders, and vulnerable communities 30–60 minutes before inundation and with regular evacuation exercises by the local disaster committees comprised of union council leaders and civil society activists. Thirdly, drainage maintenance and expansion of green infrastructure must come to the forefront in sustainable urban planning. The TMA needs to carry out detailed desilting of all municipal storm drains and secondary culverts for the entire year, particularly emphasizing high-density commercial markets, and to develop decentralized centres for picking up solid wastes to avoid dumping plastic refuse and construction rubble into natural khwar bedways. Lastly, city planners should increase the area of public green space, plant trees that are native to the region along key city corridors and enforce the use of permeable pavement in public plazas and parking lots to help reduce the urban heat island effect and reduce surface runoff velocity in Mingora.


RECOMMENDED
URBAN ADAPTATION FRAMEWORK
1
Legal & Regulatory Enforcement
Enforce strict construction setbacks along khwars.
Demolish illegal encroachments in natural floodways.
No Construction Zone (Overlay Setback)
Khwar / Floodway
2
Infrastructure & Municipal Planning
Desilt & expand primary drainage culverts.
Upgrade solid waste management to prevent blockages.
Drainage Culvert Expansion & Desilting
Improved Waste Management
3
Early Warning & Green Urban Design
Deploy community-centered cloudburst warnings.
Expand urban green cover & permeable paving.
Cloudburst Alert
Heavy rainfall expected in your area. Stay safe!
Early Warning System
Urban Green Cover & Permeable Paving

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